Space-Time Processing for MIMO Communications

Editors
A. B. Gershman and N. D. Sidiropoulos

WILEY

Contents

List of Contributors xi

Preface xiii

Acknowledgements xvii

1 MIMO Wireless Channel Modeling and Experimental Characterization 1
Michael A. Jensen and Jon W. Wallace

1.1 Introduction 1
1.1.1 MIMO system model 2
1.1.2 Channel normalization 4
1.2 MIMO Channel Measurement 5
1.2.1 Measurement system 6
1.2.2 Channel matrix characteristics 8
1.2.3 Multipath estimation 11
1.3 MIMO Channel Models 13
1.3.1 Random matrix models 13
1.3.2 Geometric discrete scattering models 19
1.3.3 Statistical cluster models 20
1.3.4 Deterministic ray tracing 24
1.4 The Impact of Antennas on MIMO Performance 24
1.4.1 Spatial diversity 25
1.4.2 Pattern (angle and polarization) diversity 26
1.4.3 Mutual coupling and receiver network modeling 28
References 35

2 Multidimensional Harmonic Retrieval with Applications in MIMO Wireless Channel Sounding 41
Xiangqian Liu, Nikos D. Sidiropoulos, and Tao Jiang

2.1 Introduction 41
2.2 Harmonic Retrieval Data Model 43
2.2.1 2-D harmonic retrieval model 43
2.2.2 N-D harmonic retrieval model 44
2.2.3 Khatri–Rao product of Vandermonde matrices 45

2.3 Identifiability of Multidimensional Harmonic Retrieval 46
2.3.1 Deterministic ID of N-D harmonic retrieval 47
2.3.2 Stochastic ID of 2-D harmonic retrieval 48
2.3.3 Stochastic ID of N-D harmonic retrieval 51
2.4 Multidimensional Harmonic Retrieval Algorithms 53
2.4.1 2-D MDF 54
2.4.2 N-D MDF 54
2.4.3 N-D unitary ESPRIT 55
2.4.4 N-D MUSIC 57
2.4.5 N-D RARE 58
2.4.6 Summary 58
2.5 Numerical Examples 59
2.5.1 2-D harmonic retrieval (simulated data) 59
2.5.2 3-D harmonic retrieval (simulated data) 61
2.6 Multidimensional Harmonic Retrieval for MIMO Channel Estimation 61
2.6.1 Parametric channel modeling 62
2.6.2 MIMO channel sounding 65
2.6.3 Examples of 3-D MDF applied to measurement data 66
2.7 Concluding Remarks 70
References 73

3 Certain Computations Involving Complex Gaussian Matrices with Applications to the Performance Analysis of MIMO Systems 77
Ming Kang, Lin Yang, and Mohamed-Slim Alouini

3.1 Introduction 77
3.2 Performance Measures of Multiple Antenna Systems 78
3.2.1 Noise-limited MIMO fading channels 78
3.2.2 MIMO channels in the presence of cochannel interference 80
3.2.3 MIMO beamforming 83
3.3 Some Mathematical Preliminaries 85
3.4 General Calculations with MIMO Applications 87
3.4.1 Main result 90
3.4.2 Application to noise-limited MIMO systems 92
3.4.3 Applications to MIMO channels in the presence of interference 97
3.5 Summary 101
References 102

4 Recent Advances in Orthogonal Space-Time Block Coding 105
Mohammad Gharavi-Alkhansari, Alex B. Gershman, and Shahram Shahbazpanahi

4.1 Introduction 105
4.2 Notations and Acronyms 106
4.3 Mathematical Preliminaries 106
4.4 MIMO System Model and OSTBC Background 108

4.5 Constellation Space Invariance and Equivalent Array-Processing-Type MIMO Model . . . 111
4.6 Coherent ML Decoding . . . 115
4.7 Exact Symbol Error Probability Analysis of Coherent ML Decoder . . . 119
4.7.1 Probability of error for a separable input constellation . . . 119
4.7.2 Probability of error for a nonseparable input constellation . . . 128
4.8 Optimality Properties of OSTBCs . . . 133
4.8.1 Sufficient conditions for optimal space-time codes with dimension-constrained constellations . . . 135
4.8.2 Optimality of OSTBCs for dimension-constrained constellations . . . 140
4.8.3 Optimality of OSTBCs for small-size constellations . . . 141
4.8.4 Optimality of OSTBCs among LD codes with the same number of complex variables . . . 144
4.9 Blind Decoding of OSTBCs . . . 145
4.9.1 Signal model and its properties . . . 146
4.9.2 Blind channel estimation . . . 147
4.9.3 Relationship to the blind ML estimator . . . 153
4.9.4 Numerical examples . . . 154
4.10 Multiaccess MIMO Receivers for OSTBCs . . . 157
4.10.1 Multiaccess MIMO model . . . 158
4.10.2 Minimum variance receivers . . . 159
4.10.3 Numerical examples . . . 161
4.11 Conclusions . . . 163
References . . . 163

5 Trace-Orthogonal Full Diversity Cyclotomic Space-Time Codes 169
Jian-Kang Zhang, Jing Liu, and Kon Max Wong

5.1 Introduction . . . 169
5.2 Channel Model with Linear Dispersion Codes . . . 172
5.3 Good Structures for LD Codes: Trace Orthogonality . . . 174
5.3.1 An information-theoretic viewpoint . . . 174
5.3.2 A detection error viewpoint . . . 177
5.4 Trace-orthogonal LD Codes . . . 182
5.4.1 Trace orthogonality . . . 182
5.4.2 Optimality of trace-orthogonal LD codes from a linear MMSE receiver viewpoint . . . 183
5.5 Construction of Trace Orthogonal LD Codes . . . 187
5.6 Design of Full Diversity LD Codes . . . 192
5.6.1 Some basic definitions and results in algebraic number theory . . . 192
5.6.2 Design of full diversity LD codes . . . 194
5.7 Design of Full Diversity Linear Space-time Block Codes for $N < M$ . . . 197
5.8 Design Examples and Simulations . . . 200
5.9 Conclusion . . . 204
References . . . 205

6 Linear and Dirty-Paper Techniques for the Multiuser MIMO Downlink **209**
Christian B. Peel, Quentin H. Spencer, A. Lee Swindlehurst, Martin Haardt, and Bertrand M. Hochwald

6.1 Introduction . . . 209
6.1.1 Problem overview . . . 209
6.1.2 Literature survey . . . 210
6.1.3 Chapter organization . . . 212
6.2 Background and Notation . . . 212
6.2.1 Capacity . . . 213
6.2.2 Dirty-paper coding . . . 215
6.2.3 Discussion . . . 216
6.3 Single Antenna Receivers . . . 217
6.3.1 Channel inversion . . . 217
6.3.2 Regularized channel inversion . . . 218
6.3.3 Sphere encoding . . . 219
6.3.4 Computationally efficient precoding . . . 223
6.3.5 Power control . . . 226
6.4 Multiple Antenna Receivers . . . 227
6.4.1 Channel block diagonalization . . . 227
6.4.2 Combined block diagonalization and MMSE THP precoding . . . 228
6.4.3 Coordinated Tx/Rx beamforming . . . 231
6.5 Open Problems . . . 234
6.5.1 Coding and capacity . . . 234
6.5.2 Partial or imperfect CSI . . . 234
6.5.3 Scheduling . . . 235
6.5.4 Resource allocation . . . 235
6.6 Summary . . . 236
References . . . 236

7 Antenna Subset Selection in MIMO Communication Systems **245**
Alexei Gorokhov, Dhananjay A. Gore, and Arogyaswami J. Paulraj

7.1 Introduction . . . 245
7.1.1 Signal and channel model . . . 246
7.2 SIMO/MISO Selection . . . 247
7.2.1 Maximum ratio combining . . . 247
7.2.2 Antenna selection . . . 248
7.2.3 MRC versus antenna selection: performance comparison . . . 248
7.3 MIMO Selection . . . 251
7.3.1 Antenna selection for practical space-time processing . . . 251
7.3.2 Antenna selection to maximize Shannon capacity . . . 251
7.4 Diversity and Multiplexing with MIMO Antenna Selection . . . 254
7.4.1 Diversity versus multiplexing . . . 254
7.4.2 Transmit/receive antenna selection . . . 255
7.4.3 Diversity and multiplexing: numerical example . . . 259

7.5 Receive Antenna Selection Algorithms . . . 259
7.5.1 Incremental and decremental selection . . . 260
7.5.2 Numerical study . . . 262
7.6 Antenna Selection in MIMO Wireless LAN Systems . . . 262
7.7 Summary . . . 265
References . . . 266

8 Convex Optimization Theory Applied to Joint Transmitter-Receiver Design in MIMO Channels 269
Daniel Pérez Palomar, Antonio Pascual-Iserte, John M. Cioffi, and Miguel Angel Lagunas

8.1 Introduction . . . 269
8.2 Convex Optimization Theory . . . 271
8.2.1 Definitions and classes of convex problems . . . 271
8.2.2 Reformulating a problem in convex form . . . 273
8.2.3 Lagrange duality theory and KKT optimality conditions . . . 274
8.2.4 Efficient numerical algorithms to solve convex problems . . . 275
8.2.5 Applications in signal processing and communications . . . 277
8.3 System Model and Preliminaries . . . 281
8.3.1 Signal model . . . 281
8.3.2 Measures of quality . . . 282
8.3.3 Optimum linear receiver . . . 283
8.4 Beamforming Design for MIMO Channels: A Convex Optimization Approach . . . 284
8.4.1 Problem formulation . . . 285
8.4.2 Optimal design with independent QoS constraints . . . 287
8.4.3 Optimal design with a global QoS constraint . . . 289
8.4.4 Extension to multicarrier systems . . . 295
8.4.5 Numerical results . . . 296
8.5 An Application to Robust Transmitter Design in MIMO Channels . . . 298
8.5.1 Introduction and state-of-the-art . . . 298
8.5.2 A generic formulation of robust approaches . . . 300
8.5.3 Problem formulation . . . 301
8.5.4 Reformulating the problem in a simplified convex form . . . 304
8.5.5 Convex uncertainty regions . . . 307
8.5.6 Numerical results . . . 308
8.6 Summary . . . 311
References . . . 313

9 MIMO Communications with Partial Channel State Information 319
Shengli Zhou and Georgios B. Giannakis

9.1 Introduction . . . 319
9.2 Partial CSI Models . . . 319
9.2.1 Statistical models . . . 320
9.2.2 Finite-rate feedback model . . . 322

9.3 Capacity-Optimal Designs 323
9.3.1 Capacity optimization with statistical CSI 324
9.3.2 Capacity optimization with finite-rate feedback 329
9.4 Error Performance Oriented Designs 331
9.4.1 Combining orthogonal STBC with linear precoding 331
9.4.2 Finite-rate one-dimensional beamforming 341
9.4.3 Further results 345
9.5 Adaptive Modulation with Partial CSI 347
9.5.1 Adaptive modulation based on 2D coder-beamformer 347
9.5.2 Adaptive modulation/beamforming with finite-rate feedback 350
9.5.3 Other combinations 352
9.6 Conclusions 352
Appendix 352
References 353

Index 357